OVERVIEW OF THE GEOLOGY AND HYDROLOGY OF THE YUCCA MOUNTAIN AREA AND A SUMMARY OF THE U.S. GEOLOGICAL SURVEY ON-GOING STUDIES FOR THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

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ABSTRACT

The U.S. Geological Survey (USGS) is a contributing scientific participant responsible for providing most of the geologic and hydrologic assessment of Yucca Mountain in southern Nevada (Fig. 1) as part of the U.S. Department of Energy (DOE), Office of Civilian Waste Management, Yucca Mountain Site Characterization Project for high-level radioactive waste disposal. This paper provides a general background on the geology and hydrology of the Yucca Mountain site and summarizes the on-going investigations within the USGS program.

INTRODUCTION

As mandated by the Nuclear Waste Policy Act of 1982 (PL 97-425) and following more than a decade of screening dozens of potential sites across the United States, three sites west of the Mississippi River were nominated for study as potential deep geologic repositories for the permanent disposal of the nation's accumulating high-level nuclear waste (HLNW). The sites were the Yucca Mountain tuff site in southern Nevada, the Basalt Waste Isolation Project (BWIP) near Hanford, in Washington, and the salt site near Hereford in the Texas panhandle. In December 1987, Congress passed the Nuclear Waste Policy Amendments Act, which further focused the search for a national nuclear-waste disposal site by naming the Yucca Mountain site as the only site to be characterized.

The Evaluation of Potential Host Rocks at the Nevada Test Site

Dating back to the early 1970's, recommendations were made to evaluate sites on or in the vicinity of the Nevada Test Site (NTS) to host the deep geologic burial of HLNW. In 1976, Vincent E. McKelvey, Director of the USGS, in a letter to Richard W. Roberts, Assistant Administrator for Nuclear Energy, U.S. Energy Research and Development Administration, made the following recommendation regarding study of the NTS for the disposal of HLNW.

> "....a comprehensive evaluation of NTS may deserve a higher priority than investigations of media such as shale, granite, or salt in other areas of the country. Because of the availability of a wealth of geological, geophysical, and hydrological data, the probability of developing an acceptable HLW repository by the late 1970's in one of the variety of media which exists at NTS appears much higher to us than in other media in more densely populated and less thoroughly understood areas elsewhere in the country."

The letter went on to discuss the assets and liabilities of sites at the NTS, a summary of which follows, with some bracketed information to indicate current knowledge.

Assets of sites at the NTS

A variety of geologic media are available for evaluations including: granite, shale, tuff, and thick unsaturated alluvium. In addition, thousands of feet of core are available for immediate measurements of heat conductivity, permeability, phase changes due to high temperature, etc.

Several natural mechanisms are operating to limit the movement of buried radionuclides. Specific mechanisms depend upon the medium and hydrogeologic setting chosen. The mechanisms include:

- Arid region with very small rates of ground-water recharge;
- Deep water tables, as much as [750 meters] deep;
- Highly sorptive properties of thick, unsaturated sediments and of saturated [and unsaturated] tuffs, very high for strontium and cesium;
- Media are available, such as granite with very small primary and secondary permeability;
- Ultimate hydrologic sumps known, namely Ash Meadows, [southern Amargosa Desert], and [perhaps] Death Valley;
- At least 100-fold dilution of any contaminants reaching the regional carbonate aquifer underlying site.

Radionuclide containment appears feasible for 10^3 to 10^5 years, depending upon the disposal medium and site chosen.

The subsurface at [places within] the NTS, [though not at Yucca Mountain], is already contaminated with nuclear waste.

A large exclusionary area already exists--NTS, adjoining Nellis Air Force Bombing Range, and other adjoining conventional weapons test ranges.

Liabilities of sites at the NTS

Detailed laboratory and field studies of rheological properties are necessary to determine the mineralogical response of the various media to the emplacement of high-

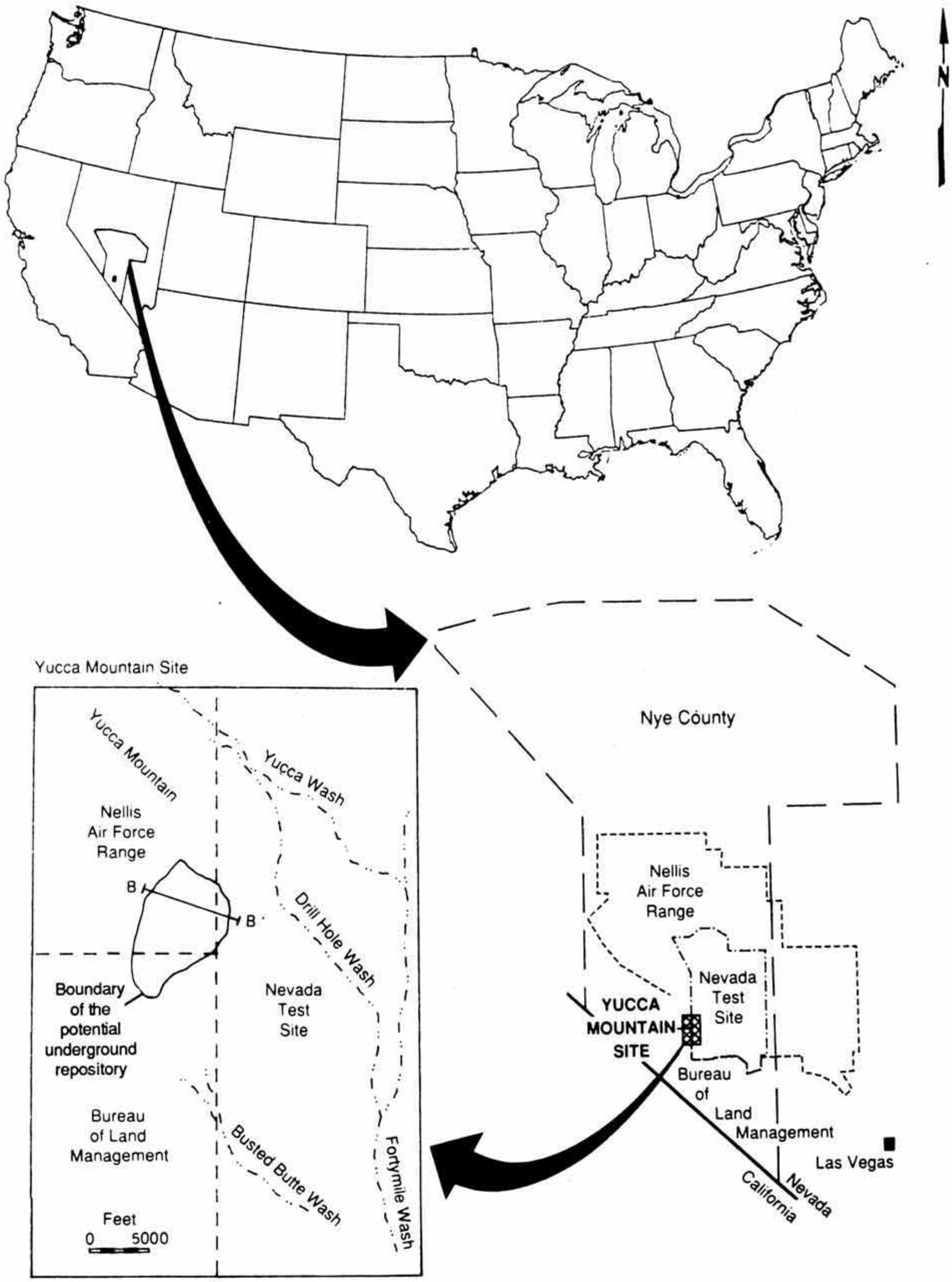

Fig. 1. Location of the Yucca Mountain site in southern Nevada showing the area of the potential underground repository. (From U.S. Department of Energy Site Characterization Plan Overview, 1988, Fig. 2-1.)

temperature HLNW canisters. Such work is necessary for media other than salt; salt has been studied.

Sorption of transuranic elements by thick unsaturated sediments and saturated [and unsaturated] tuffs [was] unstudied.

Wetter climates are likely to return within 10^4 to 10^5 years and the effects of wet climates on ground-water hydrology are unknown.

Nevada Test Site is located in seismic zone 2; hence, tectonic predictions of site stability are less certain than for sites in seismic zone 1, such as the relatively stable mid-continent.

PURPOSE AND SCOPE

The purpose for USGS studies as part of the DOE site characterization program is to develop a comprehensive understanding of the geologic and hydrologic history of the Yucca Mountain site. This information will be used by DOE to evaluate the suitability of the site for the isolation of HLNW for 10,000 years, and by the U.S. Nuclear Regulatory Commission while considering any DOE applications that may be filed to license the Yucca Mountain site for operation and eventual permanent closure.

This paper presents the general geology and hydrology of the Yucca Mountain site and summarizes the on-going investigations being conducted by the USGS for the DOE Yucca Mountain Site Characterization Program.

GEOGRAPHY AND CLIMATE

Yucca Mountain is located in the Mojave Desert of the southern Great Basin, approximately 140 km northwest of Las Vegas, and approximately 50 km east of Death Valley in southern California (Fig. 1). The mountain is a ridge with a steeply sloping western flank and a gently sloping eastern flank that rises a few hundred meters above the surrounding desert floor. The climate in the Yucca Mountain area is characterized by hot summers and mild winters, with most precipitation (principally rainfall) occurring in the winter, typical of the Mojave Desert.

Temperature has been recorded since 1988 at the crest of Yucca Mountain (A.L. Flint, USGS, written commun., 1990) near the southern end of the potential repository block. Data from this station have shown that during 1988 and 1989, July was the warmest month with 40.6°C being the highest temperature recorded (1988); July had the highest mean of the daily maximums for both years (34.3°C) and the highest monthly mean for both years (28.9°C). During the same two years, the coldest month was either January or February; January had the lowest monthly mean temperature for both years (3.9°C), and February had the lowest mean of the daily minimums for both years (-4.4°C) and the lowest temperature for both years (-13.8°C).

Estimated annual precipitation (1) at Yucca Mountain ranges from 130 mm/yr at the lower altitudes near the southern end of the mountain to more than 250 mm/yr near the northern end, where the altitude exceeds 2,000 m. In the vicinity of the potential repository block, estimated annual precipitation ranges from 155 mm to 175 mm. These values are based on a geostatistical multivariate analysis of data from 42 precipitation stations in southern Nevada and southern California with a period of record ranging from 8 years to 53 years. Precipitation at Yucca Mountain is generally in the form of short-duration (hours) high-intensity summer thunderstorms and low-intensity winter storms of long duration (days) (A.L. Flint, USGS, written commun., 1990). Of the precipitation that occurs at Yucca Mountain, it is estimated that more than 97 percent is returned to the atmosphere by evapotranspiration (A.L. Flint, USGS, oral commun., 1990).

GEOLOGY

The potential repository site is within a north-south trending ridge that is part of Yucca Mountain. The mountain is underlain by as much as 3,000 m (2,3) of Tertiary volcanic rocks that were deposited from eruptions of the Timber Mountain-Oasis Valley caldera complex (Fig. 2) from about 16 million years to 9.5 million years before present (3). These mainly silicic and volcaniclastic rocks unconformably overlie Paleozoic carbonate rocks (Fig. 3).

The broader geographic feature of Yucca Mountain was formed by a series of north-south trending fault blocks, tilted approximately 7 degrees to the east along major west-dipping, high-angle faults (4). This tilting and the resulting topographic relief were created by extentional faulting that began between 16 million and 14 million years before present (3). However, most of that relief at the mountain is known to have developed between 12.5 and 11.4 million years before present, based on the restriction of the Timber Mountain Tuff (11.4 to 11.1 million years old) to topographic basins and its unconformable position overlying the Paintbrush Tuff (2). Movement along these faults, although much less then during the period prior to deposition of the Timber Mountain Tuff, has continued into the Quaternary Period (5, and J.W. Whitney, USGS, written commun., 1989).

The Paintbrush Tuff (Fig. 3), which is the proposed host rock for a potential repository at Yucca Mountain, was deposited from eruptions of the Claim Canyon caldera (Fig. 2) between 13.1 million and 12.5 million years before present (6). This unit is subdivided into four ash-flow units: the Topopah Spring Member, the Pah Canyon Member, the Yucca Mountain Member, and the Tiva Canyon Member.

The Topopah Spring Member, which ranges from about 320 m to more than 350 m in thickness (7,8) within the potential repository block, is a multiple-flow compound

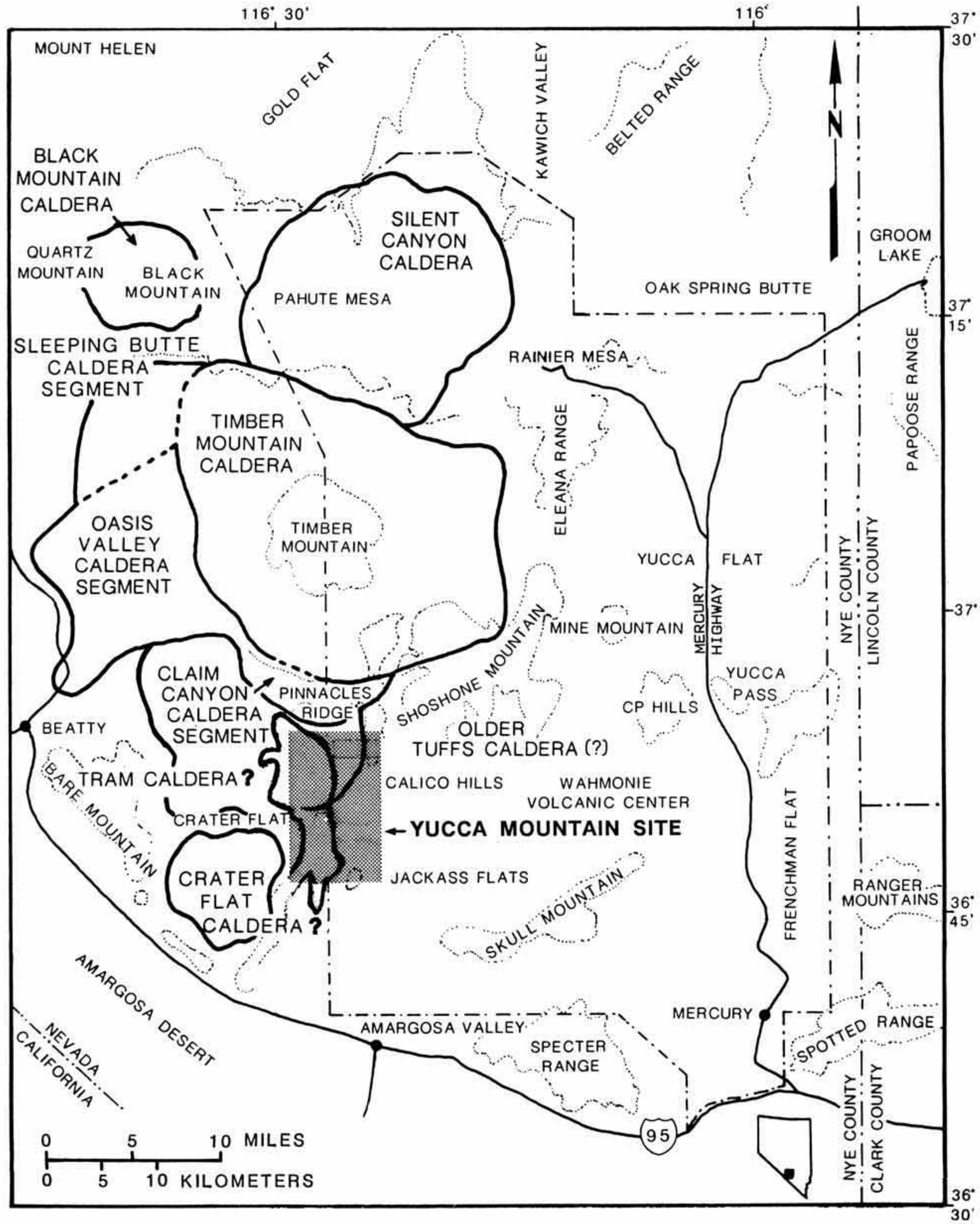

Fig. 2. Calderas of the southwest Nevada volcanic field near Yucca Mountain. [From USDOE Site Characterization Plan, 1988, Fig. 1-29 (modified from Maldonado and Koether, 1983.)]

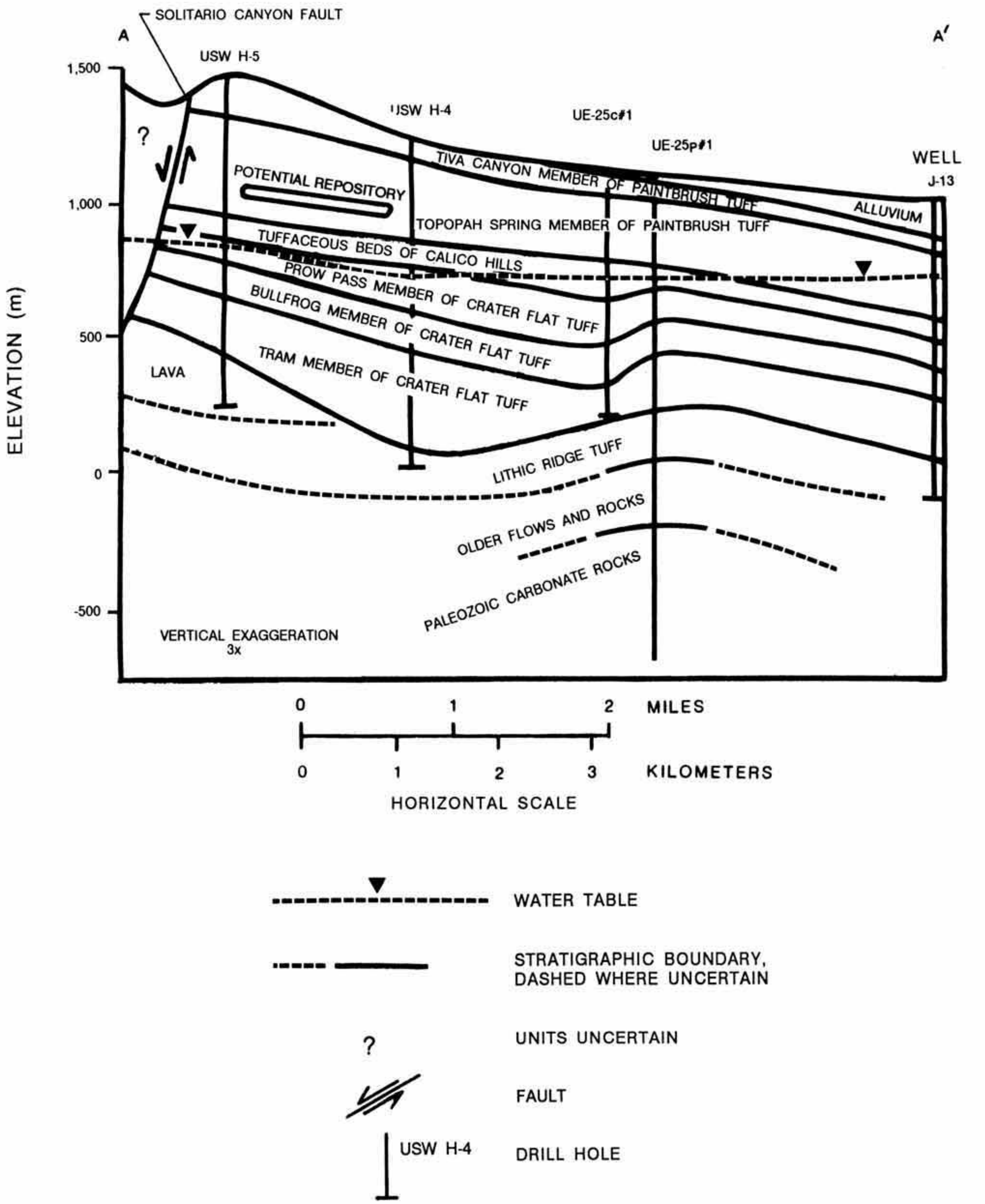

Fig. 3. Simplified stratigraphy of section across Yucca Mountain. (See Fig. 5 for location of section.) (U.S. Department of Energy Site Characterization Plan, 1988, Fig. 3-25.)

the potential repository block, is a multiple-flow compound cooling unit consisting of a densely welded crystallized center enveloped by nonwelded to densely welded glassy top, bottom, and distal edges (9). Within the Topopah Spring Member, a densely-welded lithophysae-poor section near the base has been chosen as the proposed "host horizon" for the potential repository.

Sequentially overlying the Topopah Spring Member in the Paintbrush Tuff are the Pah Canyon, Yucca Mountain, and Tiva Canyon Members. The Pah Canyon and Yucca Mountain Members (included within the Paintbrush Tuff nonwelded unit in Fig. 4) are partially to nonwelded tuffs and together range from 0 m to about 100 m thick (10,11) within the area of the potential repository. The Tiva Canyon Member, the upper most tuff in the potential repository block, is a multiple-flow compound cooling unit composed of moderately to densely welded tuffs (9,12) and within the potential repository block ranges in thickness from about 130 m to about 150 m (7,8).

Immediately underlying the Topopah Spring Member of the Paintbrush Tuff are the tuffaceous beds of the Calico Hills (Fig. 3). This unit along with the lowermost part of the Topopah Spring Member of the Paintbrush Tuff and the upper section of the Crater Flat Tuff (the Prow Pass Member and the uppermost Bullfrog Member) are also nonwelded to partially welded tuffs, and are locally highly zeolitized (13). These nonwelded and zeolitized units may provide a barrier to the downward migration of radionuclides from the site when waste canisters degrade.

HYDROLOGY

In general, the hydrologic environment at Yucca Mountain can be described as having a thick unsaturated zone, with a water table within the Tertiary volcanic rocks at depths ranging from about 300 m to about 750 m below land surface (14). Water movement within the unsaturated rocks (Fig. 4) occurs as liquid-water and water-vapor flow pervasively within the interstices of the nonwelded and welded units and locally within fractures in the welded units. Estimates indicate that recharge to the saturated zone through the potential repository block at Yucca Mountain is very limited, possibly less than 0.5 mm/yr (15). Regionally, recharge to the saturated zone beneath the mountain occurs at Timber Mountain and Pahute Mesa north of the site (Fig. 2), where altitudes range to nearly 2,300 m and precipitation ranges to greater than 350 mm/yr (16,17).

Saturated ground-water flow in the immediate vicinity of Yucca Mountain (Fig. 5) trends southerly to southeasterly toward Jackass Flats (18,19). However, regional ground-water flow (Fig. 6) trends southerly, principally toward the southern Amargosa Desert and possibly into Death Valley (17). In the southern Amargosa Desert, Franklin Lake Playa (also known as Alkali Flat) is a principal area for ground-water discharge from the regional flow system. This playa has been described as a "bypass playa" (20) because part of the ground water discharges from the playa as evaporation from bare soil and as transpiration from sparse phreatophyes in the vicinity, and part of the ground water moves to discharge areas at lower altitudes in the basin (20). The principal evidence for ground-water discharge at Franklin Lake Playa is the shallow depth to ground water (less than 3 m below land surface) and the potentiometric levels (more than 2 m above land surface) in the shallow confined beds near the northern end of the playa.

U.S. GEOLOGICAL SURVEY ON-GOING STUDIES

The USGS presently has three types of investigation underway in support of with the Yucca Mountain Site Characterization Project. They are:

On-going Monitoring Studies. Maintenance of instrumentation and data collection on these activities has been continuous in order to avoid irrecoverable losses of data that could prove important to decisions regarding the suitability or unsuitability of a repository site at Yucca Mountain. Some of these studies and their data-collection activities have been active since the late 1970's, when the Yucca Mountain site was being evaluated as part of the selection process for potential repository sites across the nation.

On-going Interrupted Studies. These studies were in progress but were halted in 1986 as a result of a DOE-imposed stop work order. The studies were restarted after the USGS Quality Assurance Program and detailed study plans were approved by the DOE.

Prototype Studies. These studies are for developing and testing methods and instrumentation that will be used during future site characterization studies.

Surface-water Monitoring and Flooding and Fluvial Debris Hazards

Beginning in 1980, the USGS conducted studies of flood potential in Topopah Wash (21) and Fortymile Wash (22) on the western side of the Nevada Test Site.

As a result of these studies, in 1983, the USGS began installing and operating a surface-water monitoring network in the vicinity of Yucca Mountain and the Amargosa Desert, and initiated debris-hazards studies in the vicinity of Yucca Mountain. The purposes of these programs are to:

- evaluate surface water as a source of infiltration to the unsaturated zone and recharge to the saturated zone;
- assess the potential for changes in the surface-water regime to affect saturated-zone flow paths and

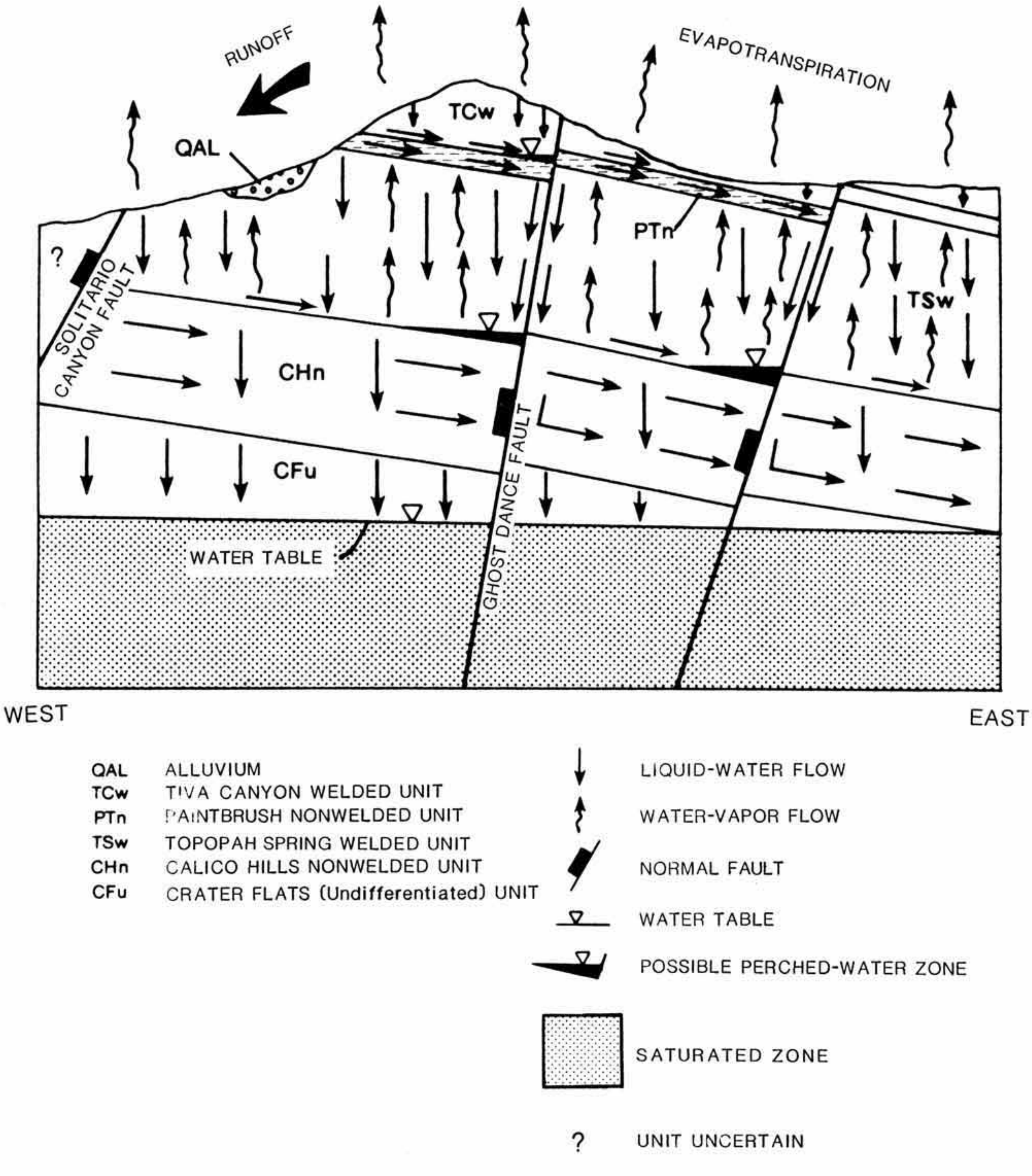

Fig. 4. Generalized east-west section through Yucca Mountain showing conceptual moisture-flow system under natural conditions. [From USDOE Site Characterization Plan, 1988, Fig. 3-40 (modified from Montazer and Wilson, 1984.)]

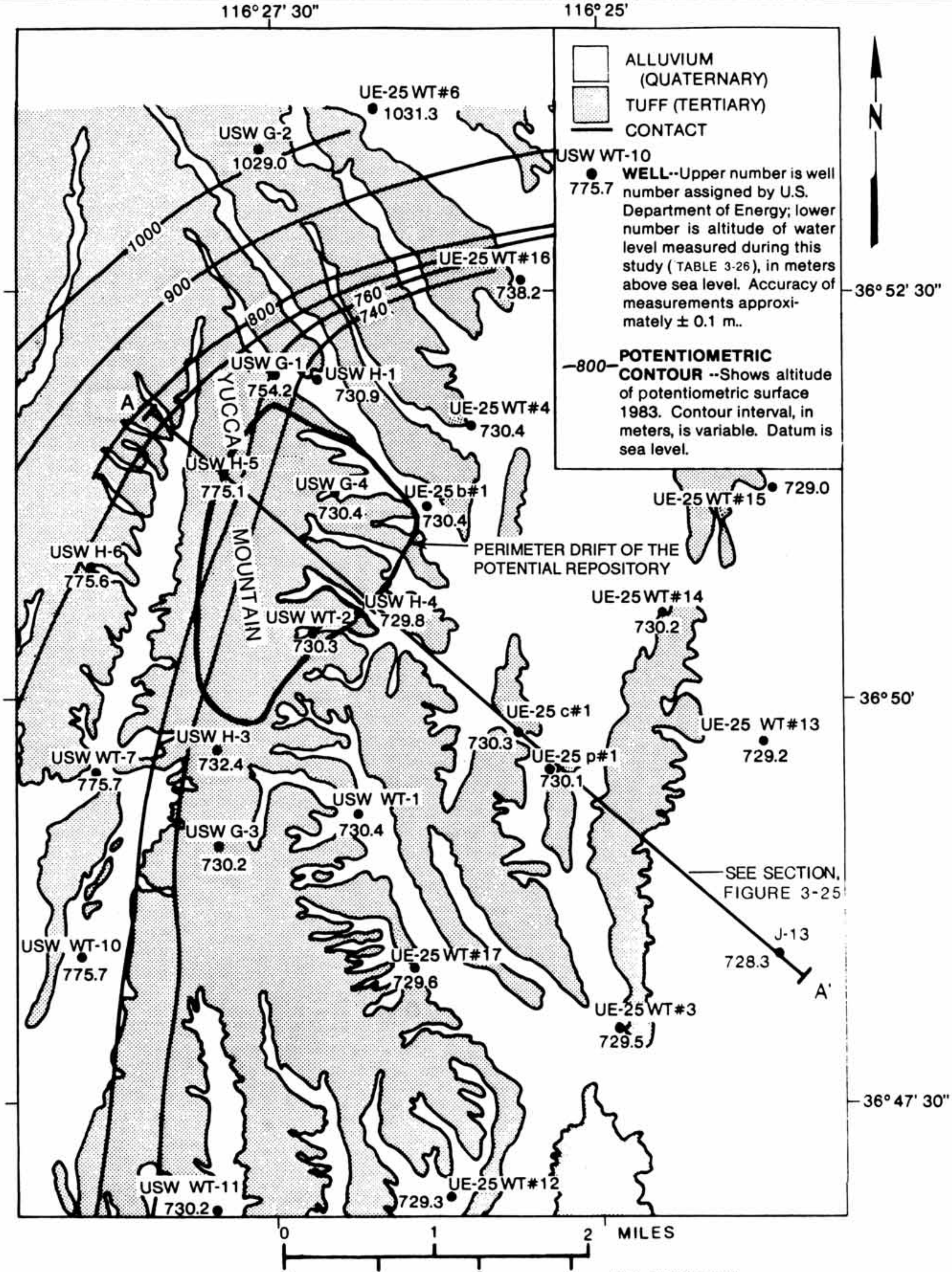

Fig. 5. Preliminary map of the potentiometric surface at Yucca Mountain. [From USDOE Site Characterization Plan, 1988, Fig. 3-28 (modified from Robison, 1984, 1986.)]

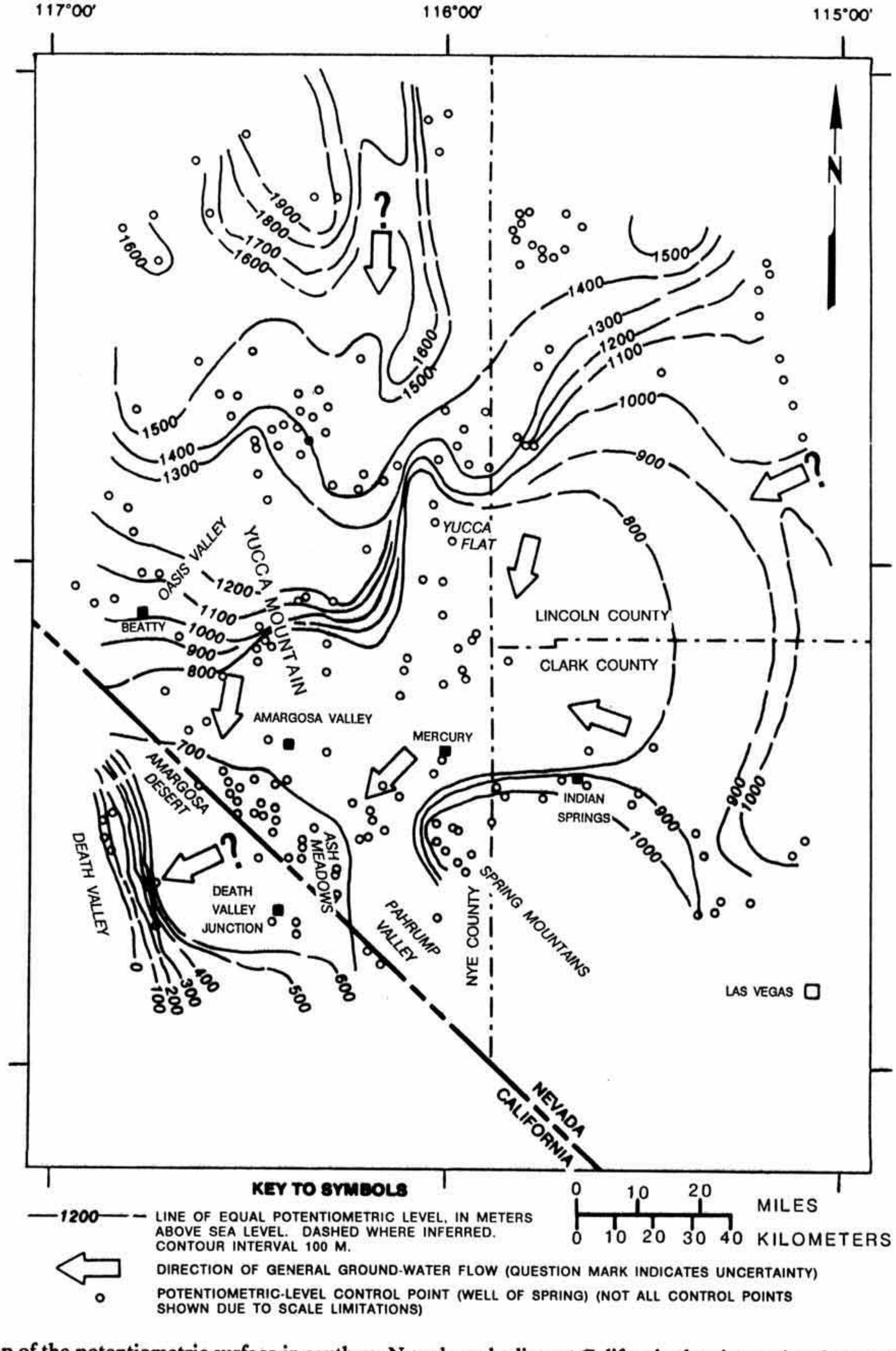

Fig. 6. Map of the potentiometric surface in southern Nevada and adjacent California showing regional ground-water flow. [From USDOE Site Characterization Plan, 1988, Fig. 3-10 (modified from Waddell et al., 1984.)]

gradients, and therefore, radionuclide transport from the site; and,

- evaluate flooding and debris-transport hazards and potential effects on potential repository facilities.

Presently, the USGS is conducting intensive studies within about 100 km of the potential repository site, including 15 gaging stations (2 stilling wells, 3 bubble gages, and 10 crest-stage gages) in the vicinity of Yucca Mountain and the Amargosa Desert. Less intensive studies by the USGS are at analog sites within about 300 km of the site. During the next 3 years, the monitoring network will be expanded to include at least 11 additional gaging stations and, if permits are granted to initiate land disturbing activities in Nevada, about 22 flume sites.

Ground-water Monitoring

Ground-water monitoring provides data that will be used to help determine the direction of ground-water movement and the range and frequency of fluctuations in water levels beneath and in the vicinity of the Yucca Mountain site and within the regional flow system. The near-site monitoring network consists of 28 wells located within about 12 km of the Yucca Mountain site, 13 of which are equipped with transducers and recorders for continuous measurements, some of these at multiple depths. Measurements have been made in these wells since installation and include manual measurement beginning in 1981 and transducer measurements beginning in 1985. When the surface-based testing at Yucca Mountain resumes, 9 additional near-site water-table monitoring wells will be drilled.

Hydrologic information on the Amargosa Desert regional ground-water basin (oral commun. J.B. Czarnecki, 1990) includes data from 1952 to present from more than 300 wells, most of which are for agricultural and domestic supply (less than 150 m deep) and mineral exploration (ranging from 300 to 600 m deep). Most of these wells were measurements by the USGS during 1984 and 1985, and about 30 wells are measured quarterly as part of the DOE Environmental Field Activities Plan.

Natural Infiltration

Since 1984, the USGS has been collecting and evaluating data on natural infiltration of water into the shallow unsaturated zone within a 25 km^2 area centered over the potential repository site. The purpose of this study is to determine the upper flux boundary for models of the thick unsaturated-zone ground-water flow system at Yucca Mountain.

Measurements of volumetric water content are being made in 74 neutron-access boreholes that range in depth from 5 m to 35 m. These holes are logged monthly to monitor moisture changes in the alluvium and underlying bedrock. Following rainfall events, logging is intensified to evaluate the moisture response to storms of high intensity and short duration, and low intensity and long duration. When drilling resumes at Yucca Mountain an additional 24 neutron-access holes will be drilled. These boreholes, in addition to providing information on subsurface moisture changes, will provide core for measuring alluvium and bedrock bulk densities and water contents in order to calibrate neutron logs to actual subsurface moisture contents at Yucca Mountain.

Meteorological Monitoring

The USGS meteorological monitoring network provides local data for the natural-infiltration program and supplements information for the DOE regional meteorological monitoring program. The USGS network is located within a 25-km^2 area centered over the potential repository site, and consists of: 2 full Penman-type meteorological stations; 86 storage-type precipitation gages located proximal to the shallow infiltration neutron access holes and at other selected locations; 5 heated tipping-bucket gages for frozen precipitation; and 6 nonheated tipping-bucket precipitation gages. This precipitation network will be expanded over the next two years to include storage gages at 24 planned sites for neutron-access boreholes and 19 additional tipping--bucket precipitation gages. In addition to precipitation gages, the meteorological network is designed to provide information on wind speed, wind direction, air temperature, relative humidity and solar radiation. This information provides essential input to many hydrological and climatological models needed for site characterization.

Site Vertical Borehole Studies

Since 1987, the USGS has been developing and testing equipment and facilities that will be used for determining the percolation of water through the unsaturated zone and the in situ permeability characteristics of the unsatu-rated rock beneath the potential repository site and vicinity. Accomplishments to date include the development of:

- a Down-hole Instrument Station Apparatus (DISA) that encapsulates thermistors, pressure transducers, thermocouple psychrometers, and equipment for sampling gases and injecting water;
- the controlled-environment instrument calibration facility in the YMP-USGS Hydrologic Research Facility (HRF) on the Nevada Test Site; and,
- the Integrated Data Acquisition System (IDAS) central computer facility at the HRF, two instrument control facilities on the east flank of Yucca Mountain at boreholes USW UZ-1 (approximately 1,300 m west of the NTS boundary) and UE-25 UZ #4 (approximately 500 m east of the NTS boundary), and

(approximately 500 m east of the NTS boundary), and a microwave telecommunication system that links the instrument control facilities to the IDAS.

Gaseous-phase and Aqueous-phase Hydrochemistry of the Unsaturated Zone

USGS gaseous-phase sampling of borehole USW UZ-1 on the east flank of Yucca Mountain (approximately 1,300 m west of the NTS boundary) for carbon dioxide and water vapor began in 1984, continued semiannually through 1989, and is presently on an annual schedule. Aqueous-phase samples were extracted and analyzed from cores from UE-25 UZ #4 and #5 (both located on the east flank of Yucca Mountain approximately 500 m east of the NTS boundary), mostly in 1985 and 1986 and continuing to the present as existing core is made available. Analyses of samples from these boreholes include:

- carbon dioxide for carbon-14 and ratios of carbon-13 to carbon-12;
- water vapor for tritium and ratios of oxygen-18 to oxygen-16 and deuterium to hydrogen; and,
- liquid water for carbon-14, tritium, ratios of oxygen-18 to oxygen-16 and deuterium to hydrogen, and cations and anions.

This information will be used to make determinations about water and gas flow paths and flow rates in the unsaturated zone.

Dust Trap Network for Modeling Soil Properties

Since 1984, the USGS has operated a network of 59 traps to collect airborne dust from a variety of settings in Nevada and California within about 600 km of the Yucca Mountain site. The purpose of this activity is to simulate dust additions to soils developed in the vicinity of Yucca Mountain and for modeling of carbonate translocation. Dust samples are collected from the network annually and analyzed for particle-size distribution, organic-matter content, mineralogy, carbonate content, soluble salts, and major oxides.

Seismic Monitoring

In 1978, the USGS began monitoring seismic activity within about 300 km of the Yucca Mountain site. The purpose of this monitoring is to provide earthquake-hazard information that can be used by DOE to determine the potential for adverse effects on:

- structures and engineered systems during the operational phase of a repository (preclosure); and
- geologic and hydrologic conditions and engineered systems during the next 10,000 years (postclosure).

The seismic network consists of 55 stations and will be expanded during the next 3 years. The expanded network will consist of 57 new digital stations, 8 strong motion detectors, 8 portable seismographs, 3 national network stations, and 7 satellite uplinks, along with the continued operation of approximately 46 of the existing network stations.

Monitoring during the past 12 years has provided the following information (Kaye Shedlock, USGS, oral commun., 1990):

- earthquakes detected within 50 km of the site have dominantly been about 1M, with a 3.5M being the largest event recorded; and,
- earthquakes detected within 300 km of the site have dominantly been about 2M, with a 4.5M being the largest event recorded.

Geodetic Leveling

This USGS activity began in 1983 and includes the releveling of the base-station network within 100 km of the Yucca Mountain site every 2 years. In addition, surveys of selected base stations using the global positioning satellite are planned. This information will be used to determine the historical and contemporary displacement across significant Quaternary faults and to determine the rate of uplift and subsidence in the vicinity of the Yucca Mountain site.

Calcite and Opaline Silica Vein Deposits

This activity began in 1982 with the discovery of calcite and opaline silica deposits in Trench 14 (not shown in figures), about 1.3 km east of the potential repository site along the northerly-trending Bow Ridge Fault (not shown in figures). Since their discovery there and elsewhere, these vein-like deposits have been a subject of controversy concerning the possible sources of water from which the deposits were precipitated. Alternatives being considered are:

- infiltrating meteoric water associated with soil-forming (pedogenic) processes, and descending beneath the soil zone into open fractures; and
- ground-water ascending through faults and fractures from a perched zone or the regional aquifer as a cold, warm, or hot spring, or from seismic pumping associated with tectonic activity.

A multidisciplinary team of scientists from the USGS and Los Alamos National Laboratory has studied the deposits, evaluating mineralogy, paleontology, geochemistry, stableisotope and tracerisotope geochemistry, and

- analyses of additional samples:
  - from the trench after it is deepened approximately 4 m, and
  - possibly from an angle borehole that will intersect the Bow Ridge Fault about 80 m below land surface.
- analyses of water in the regional aquifers and vadose water recovered from neutron-access boreholes in the vicinity of Yucca Mountain.

Other studies associated with this activity include:

- evaluation of other calcite and silica deposits in the vicinity of the potential repository block.
- analog sites in southern Nevada and California, including deposits formed by hot and cold springs, and by near-surface processes.

Analog Recharge Studies

Since 1986, the USGS has been collecting analog recharge data in two small basins, Stewart Creek and Kawich Creek, located about 100 km north of the Yucca Mountain site. These sites are considered to be representative of the range of conditions that existed during the late Pleistocene in the recharge areas for the aquifers beneath Yucca Mountain and will provide data on paleorecharge rates. Data on precipitation, surface-water flow, vegetation types, and vegetation coverage are being collected, and direct measurements of transpiration are being attempted. In addition, data on rock types, and topography will be collected.

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